EXTENDED ABSTRACT

The Evaluation of Exposure to Benzene among Children in Indoor Environments: A Review

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SUMMARY

Benzene has been measured in indoor environments for many decades and has been identified to cause variety of health effects. Children spend most of their time indoors such as daycare centre, preschool and school, they are more likely to be exposed to indoor air pollutants. This paper was aimed to review the exposure to benzene among children within indoor environments from worldwide studies from 2003 to 2018. Based on 24 papers evaluated, 54% were conducted in primary schools. The highest concentration of benzene was found in preschools in China at 148.0 µg/m3. The benzene levels were found higher in indoors than outdoors for most of the studies. Active sampling techniques were used in 42% of studies that enable the determination of acute health effects on children during short-period of exposure time. Differences in sampling techniques and durations make it hard to compare the outcomes of the studies with health-effect guidelines. This review indicated a diversity of sampling approaches and techniques, pointing to the importance of establishment of standard method for collecting and reporting data.

Keywords: Benzene, Children, Indoor Environments, Daycare Centres, Preschools

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INTRODUCTION

Children spend most of their time in indoor environments, mainly at daycare centre, preschool and school. They are more likely to be exposed to indoor air pollutants as they spend most of their time indoors and indoor pollutants are found to be two to five times higher than outdoors [1]. The levels of indoor pollution and the duration of the exposure might have a considerable impact on children's health for the rest of their lives [2]. Benzene has been classified as Group 1 to cause carcinogenic effects in humans and there is no safe exposure level of benzene can be recommended [3]. It has been measured in indoor environments for many decades and few studies on exposure to benzene among children have been reported [4-8] and variety of health effects associated with benzene have been identified includes possible childhood leukemia [9]. This paper aims to review on 24 papers that related to the studies of benzene in daycare centres, preschools and primary schools. Finally, this paper offers recommendations that can help to improve the indoor air quality study.

MATERIALS AND METHODS

A comprehensive literature search was conducted to identify any studies on children of exposure to benzene within indoor environments conducted worldwide. Original research papers published in English language academic journals were obtained by searching electronic databases including from ScienceDirect, Scopus, ProQuest and Google Scholar. The keywords used in these searches were: 'benzene', 'exposure to benzene among children', 'school', 'daycare centre', 'indoor air quality', 'benzene in indoor environments', 'health effects benzene' and 'benzene guidelines'. The results were refined to identify the studies conducted from 2003 until 2018.

RESULTS

A total of 24 papers were evaluated in this study. Based on Table I on the sampling approaches, there were 15 countries that reported on the studies of benzene in indoors. 54% were conducted in primary schools, followed by daycare centres (31%) and preschools (15%). The exposure duration and sampling methods were varied among the studies. There were two sampling approaches that being used; active sampling (42%) and passive sampling (58%). Meanwhile, the shortest and longest exposure duration were from 30 minutes [10] to 7 days per week [11-13]. For the analytical methods, most of the studies cited US EPA Compendium Method TO-17 for the analysis of benzene [6-7]. All of studies reported to use gas chromatography/mass spectrometry (GC/MS) as the principal method of analysis. Meanwhile, automated thermal desorption GC/MS and flame

Table I: Sampling approaches in determination of benzene in indoor environments

Ref	Year of study	Study Area	No of Study Site	Exposure Duration	Flow Rate	Sampling Method	Location (Month/ Season)
[13]	2013	School	Urban = 6 Rural = 6 Industrial = 6	2 weeks	n/a	Radiello passive sampler (RAD 130, activated charcoal)	Spain (Feb-Apr)
[6]	2007	School	8	4 h/7 days	0.2 L/min	Anasorb 747 charcoal tubes	Malaysia (n/a)
[17]	2011-2012	School	2	5 days/week	n/a	Radiello passive samplers	Greece (Sept-Oct/ non-heating; Jan-Feb/ heating period)
[5]	2011-2013	School	20	24 h/5 days	n/a	Tenax TA thermal desorption tubes	Portugal (Nov-March/ winter)
[4]	2009	School	Urban = 1 Suburban = 1	24 hours	n/a	3M OVM 3500 organic vapor monitors	Turkey (March/winter)
[18]	2010	School	Urban = 1 Suburban = 1	5 days/week	n/a	Radiello passive samplers	Portugal (April-June)
[2]	2011	School	2	24 h/5 days	n/a	Tenax TA thermal desorption tubes	Portugal (Nov/summer)
[12]	2003-2008	School	22	7 d/week	n/a	Radiello passive samplers (RAD 130, activated charcoal)	European cities (summer, winter)
[19]	n/a	School	Urban = 2 Suburban = 1	5 hours	66.7 ml/min	Tenax TA sorbent tubes active sampler	Turkey (winter, spring, fall)
[14]	2006-2007	School	3	24 hours	n/a	Radiello passive samplers activated charcoal (Carbograph 4)	Turkey (May-June/summer; Dec-Jan/winter)
[11]	2007	School	Urban = 1 Suburban = 1	1 week	n/a	Radiello passive sampler (RAD 130, activated charcoal)	Mediterranean cities (winter)
[20]	2003	School	Suburban = 9	4.5-day	n/a	Tenax GR thermal desorption adsorbents	USA (March-June/ spring, early summer)
[21]	2000	School	Urban = 2	31 h/5 days	n/a	3M OVM 3520 organic vapor monitors	USA (Jan-Feb/winter; Apr-May/spring)
[22]	n/a	School	6	1 hour; 8 hours	0.0931; 0.0121 L/min	Summa™ canister passive samplers	Hong Kong (n/a)
[17]	2011-2012	Preschool	1	5 days/week	n/a	Radiello passive samplers	Greece (Sept-Oct/ non-heating; Jan-Feb/ heating period)
[15]	2011	Preschool	8	24 hours	n/a	Passive sampler	China (March-April)
[23]	n/a	Preschool	Urban = 13 Suburban = 4	60 - 100 min	0.07 ~ 0.1 L/ min	Tenax TA thermal desorption tube	Korea (n/a)
[12]	2003-2008	Preschool	22	7 days/week	n/a	Radiello passive sampler (RAD 130, activated charcoal)	European cities (n/a)
[24]	2012	Daycare centre	25	7 hours	100 ml/min	2,4-DNPH coated Florisil thermal desorption cartridge	Korea (May-July)
[25]	n/a	Daycare centre	1	1 hour	100 mL/min^{-1}	Tenax TA thermal desorption tube and Carboxen 1000 60/80	Japan (Dec, March)
[7]	2013	Daycare centre	14	10 hours	1 L/min	SKC Anasorb Coconut Shell Charcoal tubes	Columbia (Autumn)
[8]	2008	Daycare centre	21	6 hours	13.5 ml/min	Summa™ canister passive samplers	Canada (Jan-Feb/winter)
[26]	n/a	Daycare centre	28	5 days/week	n/a	Radiello passive sampler (RAD 130, activated charcoal)	France (Oct-Mar/winter; Apr-Sept/summer)
[16]	n/a	Daycare centre	104	9 hours	5 and 10 mL/ min^{-1}	Tenax TA thermal desorption tube	Singapore (n/a)
[10]	2006	Daycare centre	29	30 min	n/a	Tenax TA thermal desorption tube	Korea (Jan-Dec)
[27]	2013-2014	Daycare centre	Urban = 2	n/a	n/a	Tenax TA thermal desorption tube	Poland (Dec-Jan/winter)

n/a: not available

ionization detector were used as the principal mode of detection, however they were not uniformly specified in every study.

Based on Table II, the maximum level of benzene in school was found at 19.77 µg/m3 during winter season. The study found that indoor activity, ventilation and duration of human occupancy have influenced the air quality in the buildings [14]. Benzene was found highest in preschool in China at 148.0 µg/m^3 [15], meanwhile 32.7 µg/m^3 was found in daycare center in Singapore due to the traffic emissions from outdoor and human activities [16]. The evaluation of indoor to outdoor (I/O) ratios found that majority were higher in indoors (> 1.0) compared to outdoors. High levels of benzene in indoors were related to poor ventilation, consumer products and human activities. Motor vehicle emission was found to be significant with outdoor benzene sources.

DISCUSSION AND CONCLUSION

This evaluation revealed that there is no specific regulation and standard for indoor air quality that have been reported. Comparisons among the studies

Table II: Concentrations of benzene in indoor environments (µg/m^3)

Ref.	No. of sample	Benzene (µg/m$_3$)				I/O Ratio
		AM	Median	Min	Max	
[13]	54	S1: 0.5 S2: 0.3 S3: 0.7	S1: 0.48 S2: 0.27 S3: 0.66	S1: 0.4 S2: 0.2 S3: 0.6	S1: 0.5 S2: 0.4 S3: 0.9	S1: 0.9 S2: 1.0 S3: 0.8
[6]	32	7.2	4.6	n/a	31.7	0.93
[17]	n/a	S1: 1.5[a]; 3.7[b] S2: 1.5[a]; 4.0[b]	n/a	n/a	n/a	S1: 1.7[a]; 1.2[b] S2: 1.5[a]; 1.7[b]
[5]	73	n/a	2.5	1.5	2.7	0.84
[4]	S1: 26 S2: 24	S1: 1.91 S2: 2.71	S1: 0.92 S2: 2.50	S1: 0.39 S2: 1.54	S1: 13.2 S2: 4.74	S1: 1.10 S2: 0.70
[18]	n/a	0.31	n/a	n/a	n/a	0.84
[2]	n/a	S1: <1.0 S2: 1.63	n/a	n/a	n/a	n/a
[19]	n/a	10.4	n/a	n/a	n/a	n/a
[14]	n/a	7.5[a] 19.77[b]	n/a	n/a	n/a	1.57[a] 1.20[b]
[11]	n/a	S1: 2.4 S2: 4.5	n/a	n/a	n/a	n/d
[20]	64	0.09	n/a	n/a	1.6	1.4
[21]	113	n/a	0.6[b] 0.6[c]	n/a	n/a	n/a
[22]	24	3.04	0.86	0.68	12.22	0.61
[17]	n/a	1.4[a]; 3.7[b]	n/a	n/a	n/a	3.3[a]; 2.0[b]
[15]	n/a	P1: 2.5 P2: 6.0 P3: 148.0 P4: 2.5 P5: 3.5 P6: 30.0 P7: 22.5 P8: 11.5	n/a	n/a	n/a	n/a
[23]	P1: 54 P2: 17	P1: 9.24 P2: 4.98	n/a	P1: 2.0 P2: 2.0	P1: 33.18 P2: 12.71	P1: 1.18 P2: 0.83
[12]	188	4.4	2.6	0.5	63.7	1.2
[24]	n/a	1.2[d] 1.7[e]	1.2[d] 1.7[e]	0.4[d] 0.8[e]	6.8[d] 7.9[e]	1.09
[25]	n/a	A: 10.3; 1.29 B: 8.2; <0.2 C: 6.2; <0.2	n/a	n/a	n/a	n/a
[7]	35	2.0	n/a	<LOD	4.4	n/a
[8]	21	1.8	n/a	0.9	6.3	n/a
[26]	n/a	1.4; 1.6[a] 2.0; 2.1[b]	1.4; 1.6[b] 2.1; 2.1[c]	0.5; 0.9[b] 0.5; 0.9[c]	3.7; 3.9[b] 4.4; 4.5[c]	n/a
[16]	123	NV: 25.4 HB: 17.5 ACMV: 24.2 AC: 17.9	NV: 32.7 HB: 30.5 ACMV: 28.4 AC: 21.2	n/a	n/a	n/a
[10]	183	4.2	3.6	n/d	13.1	2.2
[27]	24	S1: 1.63; 2.93 S2: 2.59; 2.11	n/a	n/a	n/a	n/a

AM: Arithmetic mean; I/O ratio: Indoor/Outdoor ratio; S: school; n/a: not available; n/d: not detectable; [a] summer; [b] winter; [c] spring; [d] day; [e] night; P: preschool; LOD: limit of detection; NV: natural ventilation; HB: hybrid ventilation; ACMV: air-conditioned and mechanically ventilated; AC: air-conditioned

were made without the consideration of the sampling methods. In general, the sampling durations were found to be different in most of the studies. This is rarely being acknowledged and is a problem for researchers globally who wish to compare their findings with previous studies. This paper indicated the need for a standard approach especially in data collection, sampling method and the correct way on how to report data.

This review showed the levels of benzene [14, 15, 16, 25, 27] were found to be higher as compared to US EPA (RfC: 0.009 ppm) [28], OSHA (1 ppm for 8-hour/5 ppm for 15-minute) [29] and WHO health-based guidelines (no safe level) [3]. However, the used of passive sampling in 58% of studies limits the determination of concentrations relevant to short-term exposure and guidelines for acute effects. Meanwhile, another 42% of studies used active sampling in their assessments. This may indicated a better support on determination of acute health effects on exposure to benzene in children. Sampling methods and sampling durations which consistent with the exposure and pollutant exposure guidelines, compatible with sampling patterns and occupant behavior, would enable a more rigorous assessment. Besides, comparison of potential health risks also can be made.

This paper also found most of the studies were conducted in school environments and only 15% were conducted in preschools and 31% for daycare centres. The highest concentration of benzene was found in preschools at 143.0 µg/m3 [15]. This finding indicated that some preschool environments may be a significant source of benzene exposure. Thus, it is important to increase the number of studies in preschool in the future. Furthermore, children in preschools and daycare centres may be more vulnerable to the effects of benzene exposures as compared to the children in schools. Thus, determination of exposure to air pollutants in these environments is especially important to the children.

The most recent study was conducted in schools located in different spatial characteristics [13]. Based on the evaluated studies, high significant levels of benzene have been related to the study areas in urban and industrial, compared to in rural area. Overall, only few studies that reported on the locations of the sampling sites. Thus it is important to acknowledge that difference in the spatial variation also can influence the benzene concentrations in indoor environments.

In summary, study related to benzene exposure in educational environments has evolved from the early year of 2000 up until recent study in 2018. Concentrations of benzene were found to be higher indoors than outdoors, especially in buildings located in urban and industrial areas, and during cold season. In some cases, these concentrations were exceeded the exposure guidelines. To enable more valid comparison among studies with exposure guidelines, a standard approach for sampling and correct way on reporting data should be introduced. Finally, greater attention should be focused on indoor air quality studies that related to air pollutants which are underreported and with vulnerable populations.

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